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UNITED STATES BUREAU OF MINES
JOHN W. FINCH, DIRECTOR

INFORMATION CIRCULAR

# HOW TO USE PERMISSIBLE EXPLOSIVES PROPERLY

BY

D. HARRINGTON AND S. P. HOWELL

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DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

# HOW TO USE PERMISSIBLE EXPLOSIVES PROPERLY[1]

By D. Harrington[2] and S. P. Howell[3]

## INTRODUCTION

Probably over 95 percent of the coal production of the United States depends upon the use of explosives before it can be placed in the railroad car at the mine, and up to the present time it has been impossible to obtain any kind of practicable explosive that isn't dangerous unless handled carefully. In other words, no "foolproof" explosives have been found to date, and inspection of the accident records of the coal mines of this country indicates that the use of explosives in coal mines has taken a sad toll of lives.

## ACCIDENTS FROM EXPLOSIVES IN COAL MINES

Of the 2,000 to 2,500 persons killed annually in the coal mines of the United States, 100 to 125 have been killed from explosives without an explosion of gas or dust; these accidents have been due to misfires, hangfires, premature blasts, or accidental setting off of explosives through carelessness or otherwise (but chiefly through carelessness in some form). In this type of accident the flame character of the explosive is not necessarily involved, although an unexpected or premature blast is initiated much more easily with black blasting powder, which has a long flame, than with a permissible explosive, which has a flame much shorter and of briefer duration. By far the greater number of such accidents are caused by black blasting powder or dynamite rather than by permissible explosive.

Although the hazard from premature blasts is much greater with long-flame black blasting powder than with short-flame permissible explosives (and this alone should outlaw black blasting powder from coal mines) by far the greater hazard from long-flame explosives (black blasting powder) is found in the fact that about one third of our coal-mine explosions have been initiated by blown-out shots or other effect of misuse of explosives, and at least 90 percent of these have been due to black blasting powder. In some

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regions with a record of numerous explosions blown-out shots (chiefly of black powder but occasionally of dynamite) have caused two thirds of the disasters. In addition, innumerable fires have been caused by black powder or dynamite shots in coal mines; one mining company operating fewer than 10 mines had a record (covering a period of several years) of more than 1 fire a week from blasting with black powder or dynamite or a mixture of the two.

Of the coal-mine explosions investigated by the United States Bureau of Mines, 1910 to November 1926, involving 144 disasters with 3,756 fatalities, 80, or about 56 percent, were from blown-out shots, and it is thought that black blasting powder was responsible for at least 70 of the 80.

The record as regards responsibility for coal-mine explosions by no means favors explosives; this fact was recognized more than 20 years ago. The problem was one of the most pressing that confronted the Bureau of Mines upon its creation in 1910; the Bureau therefore began a vigorous study of the nature of explosives and made tests to determine their suitability for use in coal mines, developing what is known as its "permissible explosives" list, though "short-flame" explosives were being used to a limited extent at least as early as 1902.

A permissible explosive is one that has passed certain tests conducted by the United States Bureau of Mines at the Explosives Experiment Station, Bruceton, Pa. After the explosive has passed these tests it is placed on the official list of explosives permissible for use in coal mines and may be sold as a permissible explosive. The word "permissible" refers not only to the explosive itself but also to the method of using the explosive underground. Thus, in addition to specifying that the explosive actually used should be similar in all respects to the sample submitted by the manufacturer for test, the Bureau specifies the use of electric detonators and states that the explosive must not be used in a frozen condition, that the quantity used for a shot must not exceed 1-1/2 pounds, and that the charge must be confined properly in a borehole with clay or other incombustible stemming. The Bureau also advocates that all coal which it is feasible to cut should be cut or sheared.

## CLASSES OF PERMISSIBLE EXPLOSIVES

The Bureau of Mines classifications of permissible explosives, as well as the conditions of use to retain permissibility, as given in Report of Investigations 3220 are:

> In order that the user of explosives may be assisted in selecting an explosive to meet a specific requirement, the United States Bureau of Mines now classifies permissible explosives in two ways, as follows: (1) On the basis of the volume of poisonous gases produced by 680 grams (1-1/2 pounds) of the explosive and (2) on the basis of the characteristic ingredient of each explosive.



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## Volume of Poisonous Gases

Most of the permissible explosives, even when properly and completely detonated in a drill hole in a coal mine, produce poisonous gases, but they produce at the same time a much larger volume of nonpoisonous gases. In order that the poisonous gases may not under normal conditions become a menace to the lives or health of miners, no explosive is now or can become permissible if it evolves upon detonation more than 158 liters (5-1/2 cubic feet) of permanent poisonous gases, as determined by tests in the Bichel pressure gage. Field tests of an explosive made under extreme conditions for the production of the greatest percentage of poisonous gases in the air show that in a narrow entry, with no ventilation at or near the face, a 1-1/2-pound charge of an explosive, which gave 158 liters of poisonous gas in gage tests, produced 0.18 percent of carbon monoxide (the only poisonous gas present) in the air when the sample was taken 2 minutes after the shot. Another sample of the air taken 2 minutes later contained 0.08 percent of carbon monoxide. It is therefore evident that where ventilation is not active, as in a closed entry, miners or shot firers should not return to the face until at least 5 minutes after a shot. At all working faces that are difficult to ventilate explosives of class A or class B should be used, preferably those of class A.

The classification on the basis of the volume of poisonous gases produced by 680 grams (1-1/2 pounds) of the explosive is as follows:

Class A, those explosives from which the volume of poisonous gases produced is not more than 53 liters.

Class B, those explosives from which the volume of poisonous gases is more than 53 liters but less than 106 liters, inclusive.

Class C, those explosives in which the volume of poisonous gases is more than 106 liters but less than 158 liters, inclusive.

## Characteristic Ingredients

Explosives are classified in accordance with their characteristic ingredients as follows:

Class 1, ammonium nitrate explosives. - To class 1 belong all the explosives in which the characteristic ingredient is ammonium nitrate. This class is divided into two subclasses. Subclass a includes every ammonium nitrate explosive that contains a sensitizer that is in itself an explosive. Subclass b includes every ammonium nitrate explosive that contains a sensitizer that is not in itself an explosive. The ammonium nitrate



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explosives of subclass a consist principally of ammonium nitrate with small percentages of nitroglycerin, nitrocellulose, or nitro-substitution compounds which are used as sensitizers. The ammonium nitrate explosives of subclass b consist principally of ammonium nitrate with small percentages of resinous matter or other nonexplosive substances used as sensitizers.

Ammonium nitrate explosives when fresh and properly detonated are well-adapted for use in mines that are not unusually wet. They are not suitable for use in wet mines; for if the contents of a cartridge of ammonium nitrate explosive is exposed for only a few hours to the damp atmosphere the explosive may so deteriorate as to fail to detonate completely, because ammonium nitrate takes up moisture readily. The redipping of cartridges of ammonium nitrate explosives aids in protecting the contents against moisture, or moist air, and the cartridges should be so stored and handled as to preserve the efficacy of the paraffinlike coating. The explosives should be obtained in a fresh condition and purchased in such quantities as will permit their prompt use. Experience at the Pittsburgh Experiment Station of the United States Bureau of Mines shows that ammonium nitrate explosives will usually detonate completely after storage for 6 months in a well-ventilated magazine.

Class 2, hydrated explosives. - To class 2 belong all explosives in which salts containing water of crystallization are the characteristic ingredients. The explosives of this class are somewhat similar in composition to the ordinary low-grade dynamites, except that one or more salts containing water of crystallization are added to reduce the flame temperature. They are easily detonated, and most of them can be used successfully in damp working places.

Class 3, organic nitrate explosives. - To class 3 belong all the explosives in which the characteristic ingredient is an organic nitrate other than nitroglycerin. The permissible explosives now listed under class 3 are nitrostarch explosives.

Class 4, nitroglycerin explosives. - To class 4 belong all the explosives in which the characteristic ingredient is nitroglycerin. These explosives contain free water or an excess of carbon, which is added to reduce the flame temperature. A few explosives of this class contain salts, or an unusually low percentage of nitroglycerin, that reduce the strength and shattering effect of the explosives on detonation. The nitroglycerin explosives have the advantage of detonating easily and of not being affected readily by moisture.

Class 5, ammonium perchlorate explosives. - To class 5 belong all explosives in which the characteristic ingredient is ammonium perchlorate.



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Class 6, gelatin explosives. - To class 6 belong all explosives in which the nitroglycerin is gelatinized with nitrocotton.

Explosives of the last class have been grouped together at the end of the list because these explosives have been specially designed for blasting rock in coal mines, although under certain conditions they have been found suitable for shooting coal also. The rate of detonation given for these explosives is that determined when the explosives were submitted for test. It should be kept in mind, however, that this rate may range from 2,000 to 5,000 meters per second.

*** explosives enumerated on the permissible lists of the United States Bureau of Mines are permissible in use only when satisfying the following requirements:

1. That the explosive is in all respects similar to the sample submitted by the manufacturer for test.

2. That electric detonators are used of not less efficiency than those prescribed - namely, those consisting by weight of 80 parts of mercury fulminate and 20 parts of potassium chlorate (or their equivalents)- and that this electric firing must be done by means of a permissible-type blasting unit.

3. That the explosive, if frozen, shall be thoroughly thawed in a safe and suitable manner before use.

4. That the quantity used for a shot does not exceed 680 grams (1-1/2 pounds) and that it is properly confined with clay or other noncombustible stemming.

5. That the diameter of the cartridge used must be not less than that designated in the column "Smallest permissible diameter."

6. That the shot is not fired in the presence of a dangerous percentage of firedamp.

7. That the shot is not a dependent shot, is not bored into the solid, and does not have a burden so heavy that the shot obviously is liable to blow out.

An extended study has convinced the authors that, despite the favorable characteristics of permissible explosives as compared with black blasting powders and dynamites, which make them much safer in use, they are still not so foolproof if improperly used as to prevent accidents, including explosions due to the ignition of gas or fine bituminous-coal dust. However, permissible explosives are so devised that they produce a relatively small,



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short-duration, low-temperature flame; they are therefore not nearly as likely to ignite inflammable mixtures containing explosive gas or coal dust as the dynamites or black blasting powders.

Permissible explosives are not so sensitive to sparks and flames as the black blasting powders or to friction or impact as most of the dynamites; moreover, they are not so insensitive (when properly handled) as to cause misfires.

Experience and experiment have amply proved that black blasting powders and dynamites are too hazardous to use in gassy mines. Permissibles are therefore extensively used in gassy mines or gassy portions of mines; their superior qualities commend them for use in all types of blasting in all coal mines, whether gassy or dusty or relatively free of both gas and dust.

Because permissible explosives are used extensively in gassy and dusty mines and generally are the only class of explosive used in very gassy mines, and thus are subjected to this hazardous condition of use, one might expect that many if not most of the ignitions of gas or dust from explosives would originate from permissible explosives. After diligent search the authors found only 13 instances of gas or dust ignition caused by or involving permissible explosives. In every one the explosive was definitely known to have been used in a nonpermissible manner - it was fired in a dangerous percentage of gas or adjacent to fine, inflammable coal dust, under one or more additional nonpermissible conditions of use. However, the Bureau has detailed records of 65 explosions involving black blasting powder only, 14 dynamite only, 10 black blasting powder and dynamite, and 11 black blasting powder and (or) dynamite with permissible explosives in the United States during the period 1908 to 1932, inclusive.

This circular is concerned mainly with the use of permissible explosives; hence but little attention is given the storage, underground transportation, or underground storage, except as they influence the quality of the explosive used and therefore are important in the proper use of permissible explosives.

Injuries to persons caused by accidents involving explosives are most frequently chargeable to improper use of the explosives; this statement also applies to permissible explosives. The greatest safety is attained when only those explosives having the greatest inherent factor of safety are used properly. Such explosives for coal mining are permissible explosives, since by certain pertinent tests permissible explosives have a factor of safety of at least 17 over common dynamite and at least 45 over the black blasting powders, on the basis of their liability to ignite gas and dust.

Permissible explosives are manufactured in a wide range of densities (or stick count), strength, rate of detonation, and diameters of cartridges (not less than 7/8 inch) and are classified on the basis of relative quantity of poisonous gases produced (class A the least poisonous gas, class B intermediate, and class C the greatest quantity of poisonous gas). Therefore,



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there is a suitable permissible explosive for virtually any blasting problem in any coal mine. The low- to medium-density permissible explosives when skillfully used have proved as good lump-coal "getters" as any nonpermissible explosive. In recent years in Great Britain such low-density "permitted explosives" have supplanted Bobbinite - a compressed pellet powder - although Bobbinite had been used in gassy mines under special conditions for almost 30 years.[4/] The authors hope that low-density permissible explosives likewise will supplant both the granular and pellet forms of black blasting powder as now used in many of the so-called nongassy coal mines of the United States.

The effect of an explosive upon the material to be blasted whether coal or rock, may be varied over wide limits by selecting the proper permissible explosive, by varying the number, position, and diameter of the boreholes, and by utilizing the proper diameter and length of the charge of the permissible explosive used. In other words, not only the character of the permissible explosive used, but also the method of using it, is important in this respect.

Where applicable, certain methods of using explosives are preferred; these will now be discussed.

## PROPER PREPARATION OF FACE

The coal or coal and rock face should be prepared in a workmanlike manner; loose roof and coal should be pulled down, corners squared, and overhang eliminated as far as feasible. It is of utmost importance that an adequate number of properly directed holes should be drilled; much of the inefficiency and danger in blasting are due to drilling too few holes, correctly placed and spaced. If the face is properly trimmed and squared cracks or crevices in the face will be disclosed, and the holes can be drilled without intersecting these cracks or crevices. If feasible the coal should be cut or sheared, or both, and the sides of the cut or shear should parallel the surveyor's sight line; this will tend to prevent the drilling of holes on the solid, and blown-out shots will be reduced to a minimum.

The coal dust produced by cutting should be allayed by the use of water on the cutter bits and at the face; rock dust should be applied to within at least 40 feet of the face as a precaution against a dust explosion.

The cuttings or "bug dust" should be entirely removed from the cut or shear, thus permitting the coal to be blasted with less explosive; this precaution is important as regards both safety and efficiency. The bug dust should be loaded out before any hole is charged; the practice of throwing machine cuttings into the gob is hazardous and in the long run is likely to be expensive.

The gage of the drill or auger should always be large enough to drill a hole of adequate diameter, so that force is not required to charge the explosive; before the hole is charged all drillings should be removed from the borehole.

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4/ Fifty-sixth Annual Report of His Majesty's Inspectors of Explosives, 1931, p. 5.



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It is usually desirable to drill holes horizontally, but when it is desirable to throw the coal forward, as where mechanical loading is employed, the holes may be angled toward the right or left.

There should always be enough holes so that a reasonable charge of explosive will properly dislodge the coal or rock; this practice tends to produce a minimum quantity of slack, increase the percentage of lump coal, and prevent blown-out shots with their numerous hazards and inefficiencies. Although the proper use of explosive promotes safety and gives a maximum percentage of lump coal the explosive alone does not fully determine the percentage of lump; loading, transportation, and handling at the tipple also are controlling or at least contributing factors.

Holes should never be drilled back of or beyond the undercut or shear; they should usually end 3 to 6 inches in front of them and should be close enough to the rib to break it loose and close enough to the permanent roof to loosen the coal from the roof but not close enough to weaken, break, or shatter it. These results can usually be obtained by those skilled by experience in the art of blasting; no person who is not skilled in this art should be allowed to use explosives in any coal mine.

## THE PRIMER AND ITS POSITION IN THE HOLE

Primers should be made with electric blasting caps, the cap secured centrally in the cartridge and pointing toward the bulk of the explosive in the primer. This is accomplished in different ways, depending upon the consistency of the explosive and the diameter of the cartridge. In the preparation of the primer the insulation of the wires to the electric blasting caps should not be damaged; otherwise the wires may be short-circuited and cause misfires. The wires should be brought off the end of the cartridge in which the detonator or cap is placed in such a way that when the primer is put into the hole last the detonator will point toward the bulk of the charge - that is, toward the bottom of the hole. The primer cartridge should be the last one to be charged, with the detonator pointing toward the bottom of the hole; experiments have indicated definitely that in the event of a blown-out shot the danger of igniting inflammable gas or dust is more remote than if the primer is placed anywhere else in the charge.

## NUMBER AND PLACEMENT OF BOREHOLES

The number of holes required depends upon the width and thickness of the face to be blasted; whether the coal is undercut, centercut, overcut, or sheared or whether a combination of these methods of mechanical mining is used; and particularly upon the character of the bed and the nature and number and location of the bands of rock or other material. There should be enough holes to bring down the coal without using an excessive amount of explosive in any one hole; generally not more than 1-1/2 pounds of explosive should be used in any one hole.



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The distance from the back of the hole to the nearest free face or machine cut should always be substantially less than, and should never exceed, the depth of the hole. Where the bed is thick or is tough or woody or where a strong or hard streak of rock, coal, or other material lies between the hole and the machine cut the holes should be arranged in two or more benches. In thin beds of coal that blasts easily narrow entries (12 feet or less) require at least 2 holes when the face is undercut, whereas wider places in the same coal probably should have at least 3 holes. In the Pittsburgh bed, where the coal is 6 to 7 feet thick and is both undercut and sheared, wide places (up to 25 feet in width) require at least 3 holes and narrow places 2 holes. If the coal is separated by a tough, center band or is thick and is machine-mined by undercutting it should be blasted in 2 benches at least, possibly 3 if the center band is particularly tough and requires separate blasting; such coal may require 1 center and 2 side holes in the lower bench and 2 corner holes in the top bench. Center-cut coal usually requires at least 2 holes in the top bench and 3 holes in the bottom bench for narrow work and an extra hole in both the upper and bottom benches for wide work. Safety considerations usually dictate that where coal is center-cut the top bench should be blasted first.

## MACHINE MINING AS AN AID TO SAFE BLASTING

If coal is machine-mined, especially if both cut and sheared, small weights - 1/2 to 3/4 pound or 1 to 4 cartridges - of explosive per hole are often adequate, the number depending largely upon the size of the cartridge and the density of the explosive in the cartridge.

Where coal that blasts easily is both cut and sheared 1 pound of permissible explosive may blast as much as 20 tons of coal; where coal is shot off the solid and is woody and difficult to blast 1 pound of black blasting powder may produce less than one-half ton of coal, much of which may be in very fine sizes. Efficiency of explosives ranges between these extremes, being higher if coal is machine-mined, friable, free of rock or bony partings, and in a bed of moderate thickness.

Any increase in the efficiency of explosives aids safety because, in general, the smaller the quantity of explosive used per ton of product the smaller the hazard in its use.

## CHARGING THE HOLE

If an adequate number of holes have been properly located and the shot firer has approached the face and assured himself that he is under safe roof and no gas is detectable he should proceed essentially as follows: If the hole has not been blown out with compressed air, scraped out, or otherwise cleaned he should remove the drillings with a scraper to prevent them from getting between the cartridges in the charge, leaving essentially no combustible material in the hole and preventing the cuttings from reducing the effective depth of the hole. He should then prove the depth, gage, and direction of the hole with his wooden tamping stick and measure the depth



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of the undercut with the stick in the same vertical plane as the hole to be certain that the hole is not on the solid and hence beyond the limits of the cut. He should charge it by placing the cartridge or cartridges in the collar of the hole essentially in the following order: If there is a half cartridge or part of a cartridge he should place the cut end in the hole first, thus insuring that this end will be in the bottom of the hole. Moist or slightly moist explosive at the cut end is not likely to impede detonation of the balance of the charge. Then, if needed, one or more cartridges should be put in the collar of the hole and the entire charge, except the primer, pushed toward the bottom of the hole and gently seated there; the primer should now be made up in the standard manner and placed in the collar of the hole, making certain that the capsule is in the outer end of the primer and pointing toward the bottom of the hole; next, the primer should be pushed gently against the remainder of the charge with a wooden tamping stick, the wires being held so they will not be kinked or abraded while charging. The remainder of the hole should be filled to the collar with incombustible stemming material, preferably a mixture of molded sand and clay, although incombustible material in paper wrappers is suitable. If paper-container cartridges of incombustible stemming are used they should be made at least 14 inches long and each cartridge broken in the middle; the broken end should be placed in the hole first to make sure that there is little or no paper in contact with the explosive. Furthermore, the weakened forward end of the cartridge will therefore upset when rammed and facilitate filling the borehole with stemming material.

Permissible explosives usually should be charged without breaking the cartridges and seldom require vigorous ramming or tamping. If a charge of high density is required the cartridges, other than the primer, should be slit and pushed firmly into place one at a time but not violently.

In placing the stemming the first portion of it should be pressed firmly or gently in place as required, but the last portion may be tamped more vigorously.

An important precaution to reduce the hazard in charging the borehole is to protect the explosive and the electric blasting cap used for firing the explosive from all impact, friction, sparks, and flames, as these are the most frequent causes of premature blasts in charging.

If permissible explosives are used instead of black blasting powder, especially black blasting powder in granular form, there is relatively little danger of ignition by sparks, flames, and their sources; this is one of the main reasons why black blasting powder should be supplanted by permissible explosives in coal mines.

## WHO SHOULD DRILL HOLE, CHARGE, TAMP, AND FIRE?

In these days of mechanical mining it is feasible in many mines to drill holes with either compressed-air or electric drills, but whether they are drilled manually or with power the drilling should be done by a special crew



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upon whom dependence can be placed to locate the holes in accordance with a standard adopted for each type of working face. Where holes are drilled by individual miners it generally is useless to expect correct location of holes; improperly located holes place upon the shot firer the disagreeable task of refusing to charge or fire them or taking a chance of losing his life if he should fire them. Many shot firers undoubtedly have been maimed or killed through holes carelessly or even maliciously loaded by persons not required to fire them.

Competent shot firers should charge and tamp holes, and their competence should be attested by a State certificate as shot firer, mine examiner, fireboss, or foreman; as a reasonably safe alternative for actual loading by a certified man the shots may be charged and the holes tamped under the immediate supervision of a man so qualified.

Decision 12 of the Mine Safety Board of the United States Bureau of Mines covers this point:

> 5. Each shot employing explosives shall be prepared and fired by or under the immediate supervision of a man having a State certificate as a mine examiner, fireboss, or foreman; and whenever conditions permit all other men than those authorized to prepare and fire shots shall be out of the mine when shot-firing with explosives is being done.

Next to firing from outside the mine when no one is in the mine the greatest safety is assured if shots are fired on the "off" shift when no one is in the mine except the shot firer; in the handling and use of explosives it is a fundamental fact that hazards to life are least when the fewest number of persons are in the danger zone. This method of firing shots prevents the fatalities and nonfatal injuries classified as gas- and dust-explosions, injuries caused by explosives, unguarded shots, returning too soon, delayed blast, hit by projected material of blast, and shot breaking through rib or pillar.

## TESTING FOR GAS

Both before and after charging a hole the shot firer should assure himself by a suitable test, such as with a permissible flame safety lamp, that no gas is present; if he finds gas before charging in quantities that indicate danger the hole should not be charged, and if he finds it after the hole is charged the shot should not be fired until after the gas has been removed by ventilation. Although permissible explosives under test conditions stand tests indicating that they do not ignite methane, there are numerous conditions in mine workings under which gas or dust may be ignited even when permissible explosives are used; the use of permissible explosives should not be relied upon to counterbalance defects in ventilation.

The time from testing for gas to the instant of firing should be as short as possible, and the intervening duties should be expedited.



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## REMOVING ELECTRICAL SHORT CIRCUIT AND CONNECTING TO SHOT-FIRING CABLE

When shots are fired by electricity the electrical short circuit on the legs of the electric blasting cap should be removed immediately before the shot-firing cable is connected to it. The shot-firing cable should be tested to make sure that it carries no current, and the uninsulated portion of the legs of the electric blasting cap should be connected to the shot-firing cable by an efficient joint.

To prevent commotion at the face when a shot is fired (caused by movement of coal or roof or escape of gases) from bringing two uninsulated portions of the shot-firing circuit together and precipitating a "break spark", the joints should be a few feet from the collar of the hole and arranged as far apart as feasible; they also should be taped and staggered to prevent their contact, but fairly good protection is offered if they are staggered and separated as far as possible even though they are not taped. Tools should be removed before this final face connection is made and the cable unreeled promptly afterward.

## UNREELING THE CABLE AND SEEKING A SAFE PLACE

The cable should be at least 100 feet long and should be kept dry and in good repair. In unreeling the cable toward the point of firing care should be taken that it touches no rails, pipe lines, electric wires, or electric machines; the best way is to hang the cable on insulators, which may be dry wooden pegs or cappieces or props.

After the shot firer has reached the point selected for firing, which is known to have a safe top and which is definitely around a corner or not in a straight line from the point of firing so that projected material from the blast will not be thrown into it, the shot may be fired. The cable should be at least 100 feet long to permit the shot firer to fire from a safe place. The battery end of the cable should be "shorted" at all times except while the shot firer has assured himself of being in a safe place and is actually firing.

## GUARDING, WARNING, AND FIRING

If no other men are in the mine and the firer is sure that the men with him are in a safe place (he should be the nearest one to the shot) he should call in a loud voice "Fire", remove the "short" from the battery end of the shot-firing cable, attach the cable to the shot-firing unit, loudly call "Fire" again, and then fire within a second or two.

If other men are in the mine all in nearby working places should be warned, and all crosscuts and other approaches to the place should be guarded; if the blast is in a face approaching other workings those in the other workings also should be warned before the shot is fired. The shot firer should then call "Fire" loudly, remove the "short" from the end of



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the shot-firing cable, attach the cable to the blasting unit, call "Fire" again in a loud voice, and then blast within a second or two. Immediately after a charge is fired the shot-firing unit should be detached from the firing cable and the firing cable "shorted."

## METHODS OF FIRING SHOTS

The type of accident that can be avoided by firing shots from outside the mine has already been indicated; this method of firing shots from outside the mine when no one is in the mine is greatly to be preferred and is practiced successfully in several coal mines in Utah, Colorado, New Mexico, and elsewhere. As with all methods, most if not all of the hazards in transportation, charging, drilling into old holes, and premature shots still exist, though they can be rigidly safeguarded; the safety records of mines using this system are remarkably good as regards blasting accidents of all kinds, including the occurrence of fires and explosions; and injuries or fatalities to workers are almost eliminated.

Other methods of firing, in the order of their preference, are:

1. Charging and firing by shot firers when all other men are out of the mine.

2. Charging and firing by shot firers on the "off" shift.

3. Charging and firing by shot firers on the regular shift.

4. Charging by miners during the shift and firing by shot firers when all other men are out of the mine.

5. Charging and firing by miners at the end of the shift or at some specified time during the shift, such as midday.

The method least to be preferred is:

6. Charging and firing by miners at any time during the shift.

Charging and firing by shot firers are in all cases preferred, as there are many advantages in all blasting operations being handled by certified or qualified shot firers; men with such qualifications are competent and are given a reasonable amount of sensible instruction and supervision. It is important that they be given such instructions and supervision; otherwise human frailties will intervene, and recklessness of various kinds creep into the work. A shot firer should examine the place for explosive gas and dangerous roof before and after shooting and should see that enough holes have been drilled and that they are properly placed. He should be relied upon to use the right amount of explosive and see that it is correctly charged and tamped. He also should be expected to adhere to safety standards, such as warning men in adjacent working places, if blasting is being done while men are in the mine, and guarding approaches to the place. Well-selected shot firers



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are more likely to fire from a safe distance than the miners and if they are carefully supervised should make sure that coal is blasted in an efficient manner, usually with a larger production of lump coal, reduction in explosive used, and minimum harm to timbers, roof, or other mining adjuncts.

## Method of Firing Shots in Utah

A detailed description of the method of firing from outside the mine, as practiced in a mine in Utah,[5/] follows:

All shots are fired electrically from outside the mine with no one underground, using 220 volts alternating current. No. 6 wire is used on the blasting circuit, except in rooms, where No. 14 wire is used. A switch in the circuit on each entry near the slope is left open when not in use. In addition, there are 3 switches in the shot-firing circuit near the manway portal; 2 of these are double-pole knife switches, and 1 is operated by a pipe gate. The switches are locked open until all shot firers are out of the mine. After the 2 knife switches are closed the gate switch is closed and locked. The circuit is then complete between the mine and the master or timing switch in the nearby check cabin.

Each of the 3 shot firers has a key to only 1 of the switches near the manway portal; all of the shot firers must therefore be out of the mine before blasting. In other words, the circuit cannot be completed in the mine until all the shot firers reach the surface, unlock their respective switches, and close them.

After the three switches have been closed the time-limit switch is ready to be operated. It is first unlocked and the plunger, which operates in a slotted 1-inch pipe, is raised and connected to the solenoid switch. The current flows through the firing circuit during the time that the plunger drops 6 feet 8 inches, which is about 0.7 second. The electric blasting caps are sometimes connected in parallel and other times in parallel-series.

Detailed information on methods of firing in other Utah mines where firing is done from outside the mine when no one is in it follows. In one mine the coal is undercut in 25-foot rooms and blasted in 2 benches - 4 holes in the bottom bench and 5 holes in the top bench. The 4 holes in the bottom bench are connecced in series, the 5 holes in the top bench are connected in another series, and the 2 series are connected in parallel. The 2 center holes of the 4 lower holes are fired by instantaneous electric blasting caps, and the 2 side holes have first-delay electric blasting caps; the center hole of the upper 5 holes has first-delay, the 2 intermediate holes have second-delay, and the 2 side holes have third-delay electric blasting caps.

5/ Parker, D. J., Safety Practices at Mine 1, Spring Canyon Coal Co., Utah: Inf. Circ. 6675, Bureau of Mines, 1932, 10 pp.



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In another mine where the coal is undercut 4 holes connected in parallel are sometimes used for blasting in 1 bench. At other working places in the same mine coal is blasted in 2 benches - 4 holes for the bottom bench and 4 holes for the top bench - and the holes are connected in parallel-series with 2 electric blasting caps in each series. In another mine coal is undercut and blasted in 2 benches with 4 holes in each bench; all holes are connected in parallel.

Live current is used for such blasting; the voltage should always be adequate so that when any holes are connected in series or parallel-series at least 1.5 amperes are available for each electric blasting cap, and when parallel connections are used at least 1 ampere is available for each electric blasting cap. The voltage required varies with the resistance in the shot-firing circuit, and this depends upon the gage of copper wire used and the distance between the firing switch and the working faces. To prevent misfires a current not less than that specified above must be provided. It is well to keep the voltage as low as is feasible to prevent loss of current through leakage along the shot-firing circuit.Power need not be applied in the shot-firing circuit as long as 0.7 second (700 milliseconds, a millisecond being 1/1000 of a second) even when electric blasting caps are connected in series, because 5 milliseconds have proved adequate in tests where the source of power was a powerful, manually operated shot-firing unit of the generator type. With a controlled current value certain types of instantaneous electric blasting caps do not fire in less than 7 milliseconds. The combination of a 5-millisecond timing switch in the shot-firing circuit at the source of power with this particular type of electric blasting cap insures that there is no voltage (or current) on the shot-firing circuit at the instant the shots explode. This reduces substantially the opportunity for ignition of inflammable gas or dust mixtures by a break spark on the firing circuit caused by commotion at the face due to the blast.

## RETURN TO FACE AFTER BLASTING

After a blast it is unwise to return to the face immediately, even though the shots appear to have fired properly, because occasionally a single shot may explode twice. The reason for this double fire is obscure, but it has been attributed to insensitive or deteriorated explosive, usually caused by improper storage; only a portion of the charge explodes at first, and later another portion is ignited by the heat or burning of the first explosion. Weak electric blasting "caps" may cause a somewhat similar result; these caps should be of No. 6 grade or stronger. No cap of less than No. 6 grade is manufactured in the United States for use in this country. Possibly in these double-fire cases the charge did actually explode completely, but the material did not yield to the high pressure within the borehole until later, and this delayed yielding sounded like a second explosion. There are numerous other reasons why one should not return to the face immediately after shot-firing. The smoke and dust may so obscure the roof or face that immediate approach is hazardous, the partly loosened material may not have finished falling, or the explosives fumes and dust may not have been adequately diluted by ventilation, and noxious gases, fumes and dusts may be



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present. Dangerous gases are least likely to be encountered if a permissible explosive of class A is used and if the weight of the charge is small (preferably less than 1-1/2 pounds per hole).

## MISFIRES AND HANGFIRES

### Prevention of Misfires

Every effort should be made to prevent misfires. Those known to have occurred must be handled almost invariably, and handling these is always hazardous. Sometimes, however, misfires, especially partial misfires, are not detected at the time of firing but may be encountered by drilling into them possibly months or even years later. Whether the misfire is known or unknown, the explosive may be hidden in the coal or rock and remain a continual menace until it is either discovered and removed or until it is burned with the coal, with or without an explosion.

Misfires can be prevented by selecting proper explosives and keeping electric blasting caps in first-class condition by proper storage; using the explosive before it has aged unduly; and correct storing, priming, charging, and firing of the explosive. The officials of each mine and of each mining company should maintain a detailed record of the number of holes fired on every shift, number of misfires, and number of accidents in handling misfires. Such a record would show type of explosive, make of electric blasting cap, type of primer, and method of firing most likely to produce misfires; number of accidents chargeable to each method of handling misfires; and the miner or shot firer responsible for misfires. These data should aid in gradually evolving the best type of explosive and electric blasting cap for use in the particular mine, the safest method of firing, the best type of primer, and the safest method of handling misfires for each condition encountered. The publication of such details by the management would contribute materially to the prevention of misfires in mining.

Careful electric shot-firing offers the best means of reducing the number of misfires, but electric firing is by no means foolproof and should not be inaugurated without proper education and instruction of mine workers, especially supervisors and shot firers. Avoidance of misfires in electric firing presupposes the use of a good type of explosive in good condition, use of well-prepared primers, skill in charging and tamping the holes, a good firing circuit, and a blasting unit of adequate capacity.

Misfires in electric firing may result from conditions outside the borehole, such as poor methods of storing explosives, damp or deteriorated explosives, open circuit, short circuit, or too much resistance in firing line, or not enough capacity at source of electric current. These possible defects should be investigated first, especially the electrical defects; for this purpose a circuit tester is useful. Care in making connections, inspection and proper maintenance of shot-firing cables, and periodic testing of the blasting unit to make sure that it is up to capacity will usually



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prevent misfires from this source. When the shot firer is sure that the cause is within the borehole the misfire must be handled, preferably by the shot firer, by no means a desirable duty.

## Return to a Misfire

As soon as one or more attempts have been made to fire a shot electrically the blasting unit should be disconnected promptly from the shot-firing cable and the end of the cable short-circuited.

The time interval before return to the face provided for in most State laws or company rules should be observed, but in the absence of such laws or rules 15 minutes at least should elapse before return; when conditions permit, this minimum should be greatly increased not only because of the possible shot-firing hazards but also because of possible loose roof or coal or dust and gases in the air if other holes had fired.

Any misfire may prove to be a hangfire or a delayed blast; hence a reasonable time should elapse before return to a misfire. The belief that at least 8 hours should constitute the "reasonable time" is warranted.

## Handling Misfires

State regulatory agencies may prescribe the method of handling misfires. Such rules usually state that in coal mines a new hole shall be drilled alongside the misfired hole and approximately 1 foot from it, so started and slanted that there will be no chance for the new hole to intersect the misfired hole; the new hole should be charged lightly and blasted in the usual manner. Company rules are sometimes more rigid than State requirements and, of course, should in no case be less rigid. The object of the blast in the new hole is to expose the charge in the misfired hole so that it can be recovered completely; the charge in the second hole, therefore, should be light to avoid exploding the misfired hole. The second hole should be on the free side of the misfired hole; the direction of the hole is more important than the distance from the misfired hole, as it is important that the second hole should not be drilled into the first hole. The primer of the first hole can be recovered more readily if the wires of the electric blasting cap of the misfired hole are anchored outside the hole.

Misfires should be handled only by competent persons (shot firers or supervisory officials) and, where at all feasible, under the direction or immediate supervision of the foreman or assistant foreman. They should be handled preferably on an off shift, and until they are recovered no person or persons should be allowed to work in the working place in which they are located.

Where regulations permit and water is available at the face stemming in misfired holes may be removed carefully with water under pressure applied at the hole through a rubber hose; the pressure, however, should not



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be excessive. This method is facilitated and made less hazardous by the general use of sand or a mixture of sand and clay for stemming and by special incombustible indicating materials in the stemming next to the explosive, such as iron oxide; or if wrappers are used on the stemming a distinctive color of stemming in the first cartridge of stemming may be placed in the hole or a distinctive color used for the paper of that cartridge. When the stemming is washed out and the cartridge exposed a new primer may be inserted, the hole restemmed, and an attempt made to fire the charge in the usual way. This work should be done without undue delay; otherwise the water may so desensitize the front of the explosive charge that it will not explode completely, if at all. The stemming of the explosive should never be removed with a drill, auger, or other metal tool, but when the stemming is being removed by water the operation may be facilitated by the use of a long wooden spoon. Neither the charge of explosive nor any portion of it should be removed from the hole; pulling a charge from a misfired hole by the lead wires is especially dangerous.

Misfires should occur no more frequently than 1 for every 5,000 shots, or 0.02 percent of the number of shots fired. If they occur more frequently something is wrong with the explosive, the electric blasting cap, the method of preparing the primer, the method of charging the hole, the firing circuit, or the blasting unit, and an investigation should be made to determine just where the trouble lies; possibly the entire blasting system is at fault because it is not applicable to the conditions at hand.

## NOXIOUS-GAS HAZARD FROM EXPLOSIVES

Permissible explosives when detonated give off gaseous products of combustion, a small to moderate percentage of which is carbon monoxide, depending upon the class of explosive used. Most permissible explosives, even when properly and completely detonated in a drill hole in a coal mine, produce the poisonous gas carbon monoxide and a much larger volume of non-poisonous gases. Permissible explosives, however, give off much less dangerous gas than other explosives used in mining and quarrying. In order that the poisonous gases may not become a menace to the lives or health of miners under normal conditions, no explosive can become permissible if upon detonation of 1-1/2 pounds it evolves more than 158 liters (about 5-1/2 cubic feet) of poisonous gases, as determined by tests in the Bichel pressure gage. The classification of permissible explosives on the basis of the volume of poisonous gases produced by 680 grams (1-1/2 pounds) of the explosive is as follows: Class A explosives, from which the volume of poisonous gas produced is not more than 53 liters; class B explosives, from which the volume of poisonous gas is more than 53 but less than 106 liters, inclusive; and class C explosives, from which the volume of poisonous gas is more than 106 but less than 158 liters, inclusive.

Where ventilation is sluggish, miners or shot firers should not return to the face for at least 5 and preferably as much as 15 minutes after a shot, even when permissible explosives have been used; at all working faces with little or no circulation of air explosives of class A or B should be used,



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preferably class A. The quantity of noxious gas produced is directly proportional to the quantity of explosive used; therefore the efficient use of explosives is highly desirable from this standpoint alone.

Irrespective of the efficiency of ventilation, however, it is difficult to prevent poisonous gases from remaining in the voids in a pile of blasted coal or rock; ventilation of these voids to drive out the noxious gases has in some cases been promoted by sprinkling the pile with water. When conditions permit it is well to blast the coal some hours before it is loaded - one of numerous reasons for firing shots between the regular shifts.

Compared with other explosives the least poisonous gas is produced by firing gelatin dynamites, ammonia dynamites, and class A permissible explosives, but the unsuitability of gelatin and ammonia dynamites in other respects does not commend them for use in coal mines.

Black blasting powder, in any or all forms, is likely to produce considerable carbon monoxide and some hydrogen sulphide; the hydrogen sulphide, however, probably does not persist for long, as it has a tendency to "break down", especially under moist or wet conditions. The black blasting powder known as "pellet powder" is by no means free from many of the hazards associated with granular black blasting powder; numerous cases of suffocation or sickness from breathing the fumes after blasts of this explosive have been reported. Unquestionably, some of the trouble is due to the widespread opinion among users and proponents of this explosive that the noxious gases produced are not hazardous; hence men return too soon to the face after blasting. The quantity of noxious gases produced by this explosive is probably enhanced by the paraffin-paper wrapper; improvements in pellet powder are claimed to have resulted from either a reduction in the quantity of paraffin on the wrapper or a change in the quality of the paraffin used. No general statement regarding these features is warranted at this time, except that apparently there is considerable difference in the quantity and composition of gases produced from pellet powder made by different manufacturers or from different grades of pellet powder made by the same manufacturer or from any grade of pellet powder under certain conditions of use. In the near future some competent agency should remove this question of noxious gases produced by pellet powder from the field of opinion, and possibly prejudice, into the field of certainty by making adequate tests under operating conditions. At present pellet powder lacks much of being a desirable explosive for use in underground operations, not only as to irrespirable gases evolved but also as to the hazard of starting fires or explosions by ignitions of gas or dust or both.

Straight nitroglycerin dynamite should never be used underground or in confined or poorly ventilated places; the high percentage of carbon monoxide produced renders it decidedly unfit for such uses. Numerous deaths have occurred where this type of explosive has been used in mines and to some extent in quarries.



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## SMOKE PRODUCED BY EXPLOSIVES

The smoke produced by permissible and other explosives depends in part upon the brand of explosive used butlargely upon the conditions of use, including storage. If the shot is confined properly in a borehole and fired with a suitable primer a minimum of smoke should be produced. Smoke, in addition to being disagreeable and possibly hazardous to breathe, reduces visibility. Therefore only permissible explosives, which in practice produce the least smoke, should be used provided they are suitable otherwise; moreover the workers should not return to the face immediately after a shot is fired, and ample ventilation currents should be provided to move or at least dilute smoke promptly and efficiently.

## POSSIBILITY OF DEVISING BETTER PERMISSIBLE EXPLOSIVES

The question frequently has been asked as to the possibility of devising a permissible explosive that will ignite neither gas nor dust, regardless of the conditions under which it is used; the characteristics of explosives are such that as yet no such explosive has been devised or is likely to be devised in the immediate future. Sensible mining men therefore will use due caution in the firing of any kind of shots at any time, as there is no such article as a perfectly safe explosive.

The energy of a permissible explosive, like that of other explosives, results from the almost instantaneous production of a very large quantity of highly heated gases which, when properly confined, provide the pressure that brings down the coal or rock; the high pressure of the gas is due chiefly to the heat of the gases, and reduction in temperature is almost sure to reduce the strength of the explosive correspondingly. Hence, any reduction in strength would be balanced by an increase in the quantity of explosive used per hole, and any gain in safety through reduction in temperature would be lost in large part because of the larger quantity used. More important, however, is the fact that numerous efforts to improve the safety and working efficiency of permissible explosives to the point where ignition of gas is impossible have resulted in types of explosives so insensitive to detonation that misfires and partial misfires occurred frequently and the explosive was unsuitable from the standpoint of sensitiveness to detonation. Until substantial assistance can be expected in this direction, how can maximum safety in the use of permissible explosives be obtained? Obviously, at present about the only recourse is to use suitable safeguards against the explosives. Several of these, which can be applied easily, are set forth in detail in this publication; adequate instruction, supervision, and discipline in their use makes them effective.

## SPECIAL APPLICATION OF SHEATHED EXPLOSIVES

An unusual hazard obtains where a crevice intersects the borehole and a free face. Sometimes these crevices exist before the hole is drilled; sometimes the crack is opened by firing nearby holes; and sometimes in friable coal which is undercut a portion of the coal drops and opens a crevice, even



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after the hole is charged, if it is not fired promptly. Some such crevices may be observed easily, and others are difficult to detect; the holes in which crevices are found should be inspected carefully, if necessary using a special tool such as a rod having a sharp side projection or a mirror. The hazard arises from the fact that upon detonation of a charge the gases escape forcibly and readily into the atmosphere through the crevice and are likely to ignite inflammable gas or dust mixtures if they are present. A measure of protection against this hazard is afforded by enclosing cartridges of permissible explosives in a sheath of special-quality sodium bicarbonate, as is done in Great Britain, or of calcium fluoride, sodium chloride, and plaster, as is done in Belgium; the sheath ordinarily is one-eighth inch thick, and the "sheathing" is done at explosives factories.

Explosives so protected are larger in diameter, heavier, and cost more than unsheathed explosives. Limited tests show the sheathed explosives to be little less efficient than unsheathed explosives but much less likely to ignite gas or dust when the explosive is used in relatively large quantities per hole.

Tests abroad have shown that the "limit charge" of sheathed permitted explosives is 2 to 3 times as much as that of unsheathed permitted explosives. In Belgium sheathed explosives represent more than 30 percent of all explosives used to bring down coal. Sheathed explosives would undoubtedly be much safer than ordinary explosives where conditions demand or are thought to demand large charges (more than 1-1/2 pounds per hole); they also would reduce the hazard if used for blasting in chutes in pitching coal beds where the accompanying hazards do not permit the drilling of holes or the proper confinement of a charge in a hole.

Users of explosives should keep sheathed explosives available for these special applications; it is not known whether explosives manufacturers in the United States make sheathed explosives for these purposes, but undoubtedly they would make them if a real demand should arise. The experience of Great Britain and Belgium with sheathed explosives appears to indicate that safety could be increased in connection with some abnormal types of blasting in the coal mines of the United States if sheathed explosives were used.

## CONDITIONS UNDER WHICH PERMISSIBLE EXPLOSIVES SHOULD BE USED

### Permissible Explosives Should Not Be Fired in a Dangerous Percentage of Firedamp

Decision 12 of the Mine Safety Board of the Bureau of Mines states:

> 3. Before and following each shot in gassy and slightly gassy coal mines examination for gas shall be made with a permissible flame safety lamp or permissible equivalent, and



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4. If more than 1-1/2 percent of inflammable gas is found, in the quantity and by the method specified in Mine Safety Decision 9, the place shall be considered to be in a hazardous condition and before another shot is fired the gas shall be reduced by ventilation below the percentage and quantity specified in Decision 9.

Decision 9 of the Mine Safety Board of the Bureau of Mines states:

5. If the air in any unsealed place, when sampled or tested in any part of that place not nearer than 4 feet from the face and 10 inches from the roof, shall be found to contain -

(a) More than 1-1/2 percent of inflammable gas, the place shall be considered to be in hazardous condition and require improved ventilation, and

(b) If more than 2-1/2 percent of inflammable gas is found, the place shall be considered dangerous, and only men who have been officially designated to improve the ventilation and are properly protected shall remain in or enter said place.

If control of ventilation were always so perfect that there would never be any inflammable gas in a place in which blasting is done the hazards of gas or dust ignition with blasting would be confined to the ignition of inflammable mixtures of dust and air, in itself no negligible hazard. Experience has amply demonstrated that such conditions are not attained in practice; far too frequently a dangerous percentage of gas or of gas and dust is present when shots are fired. After a gas ignition or a gas explosion it has frequently been found that, although the place was tested and found clear of gas upon completion of charging the hole, during the interval between testing and firing the shot the ventilation was deranged by a fall, an open door, or otherwise, and at the instant the shot was fired explosive gas was present; if several shots are fired one after another either with or without the use of delay detonators explosive gas or dust or both are likely to be present after the first shot is fired. Likewise, it is not uncommon to find after a gas ignition or gas explosion either that no test for gas has been made or that testing has not been done properly; moreover blasting has been done when explosive gas was definitely known to be present, many persons through ignorance or otherwise placing undue confidence on the safety features of permissible explosives.

The blasting operation should be conducted so that the ignition of gas will be as unlikely as is humanly possible - the place to be blasted should be adequately ventilated and carefully and properly tested for gas immediately before the shot is fired.

Rock-dusting to guard against ignition of inflammable coal dust. - All coal dust, except possibly that from some grades of anthracite, is definitely inflammable; this fact should at all times be recognized, and dust ignition and propagation by gas explosion or directly by explosives should be prevented.



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The Bureau has a record of a "bulldozing" shot which threw dust into suspension to be ignited by a live current used to fire the shot of a permissible-branded explosive. The explosive was not in a borehole and was therefore not confined properly; hence it was not used in accordance with the permissibility requirements of the Bureau of Mines. Blockholing should have been done and the shot fired with a permissible shot-firing unit which provides an electric current not potent enough to ignite gas or dust. The Bureau has a record of two other gas and dust explosions in which permissible explosives were used; it was uncertain whether gas or dust was ignited (either may have been) and whether the ignition was caused by a blown-out shot or the electric current used for firing. The propagation of the explosion by dust could have been eliminated or greatly restricted if rock-dusting had been adequate (see Bureau of Mines Report of Investigations 2606 and Information Circular 6030). Rock-dusting the rooms and scattering rock dust in the vicinity of shots, in addition to rock-dusting all entries, slopes, and passageways, probably would have prevented much of the damage in these instances. Rock-dusting is very useful if shots are improperly confined in boreholes, if holes are not correctly placed, or inflammable gas is present, but it certainly should not be used as a "cloak" for dangerous practices in the use of explosives or of dangerous types of explosives to obtain less slack or more lump coal.

## Proper Confinement of Charge in Drill Hole

In accordance with Decision 12, item 1, of the Mine Safety Board of the Bureau of Mines -

> 1. Each charge shall be in a hole properly drilled and stemmed with incombustible material.

The active list of permissible explosives as of August 1934 (Report of Investigations 3259) stipulates -

> 4. That the quantity used for a shot does not exceed 680 grams (1-1/2 pounds) and that it is properly confined with clay or other incombustible stemming.

In other words, the charge of explosive must be so isolated from inflammable gas or inflammable dust mixtures that the shot will not ignite these mixtures.

It has long been recognized that one of the most hazardous conditions that attend blasting is a blown-out or "windy" shot, and this is likely to occur frequently when blasting off the solid. As shots in blowing out commonly tear away the collar of the hole and eject the stemming from it, this type of shot is considered exceptionally hazardous. Unquestionably it is hazardous; so also are other types of blown-out shots.

Shots that blow out through the collar of the hole may be prevented by blasting with an adequate number of holes and by not requiring the explosive to handle an excessive amount of burden; one way of accomplishing this is to



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undercut or shear the coal where at all feasible and to use enough of the most effective and efficient incombustible stemming material. The Bureau of Mines advocates that clay, sand, rock dust, or combinations of them fill the requirements because they are incombustible stemming materials. Recent tests in Great Britain have indicated that a 3:1 mixture of moist sand and clay "used neat" (that is, without a wrapper and prepared as "dummies") is not only an efficient but also a practicable and readily available type of incombustible stemming. If blown-out shots could be prevented manifestly there would be no ignitions of gas or dust from this cause, regardless of the kind or type of stemming used.

Under some conditions shots may also blow out the back of the hole, ignite inflammable gas or dust, and fatally injure persons in the vicinity. As a precaution against this type of blown-out shot the back of all holes which approach open working places - this is most frequent in "holing through" crosscuts, rooms, or headings to adjacent workings - should as far as feasible be drilled so that as much stemming can be placed in the back of the hole as in the front; that is, such holes should be considered as having two ends, each of which must be stemmed. In fact, when holing through, a hole frequently does have two open ends.

In another type of blown-out shot the charge is placed so close to a free face that when the shot is fired it blows out sidewise, downward, or upward because of the inadequate burden in that particular direction, with the possibility of igniting inflammable mixtures of gas or dust. If the bottom of the shot hole is placed too close to an undercut, overcut, or shear or if there is a crack or crevice or open cleat from the end or approximately the end of the hole to the undercut, overcut, or shear the shot may blow through with disastrous results.

This condition is likely to occur if dependent shots or possibly those using delay detonators with two or more delays to the same face are fired, because a previous shot has so dislodged, removed, or loosened what should have been the normal burden for the succeeding shot that the succeeding shot may blow out. On occasion this burden may be removed to the extent that the succeeding shot is actually fired in the open. Moreover, a blown-out shot is likely to occur when two or more holes in the same working place are charged before the first hole is fired, even though each hole is fired separately. The best precaution to prevent a blown-out shot due to an adjacent shot is to charge and fire the first hole before the second hole is charged, to charge and fire the second hole before the third hole is charged, and so on until all shots in the place are fired. In this way no improperly placed hole need be charged, and there will be no charged hole requiring a choice to be made between handling it as a misfired hole or firing it. Sometimes the safest procedure is to fire the several holes simultaneously.

## First-Class Condition of Explosive Required

One of the permissible conditions of use of a permissible explosive is "that the explosive is in all respects similar to the sample submitted by the manufacturer for tests."



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Every explosive submitted to the Bureau of Mines for permissibility tests and placed on the active permissible list has certain basic chemical and physical characteristics. Chemically the components should be of the same kind and proportions and mixed in the same sequence and manner as the explosive on which the Bureau permissibility tests were made. Physically the explosive must for each size of cartridge be within certain tolerances of weight and character of wrapper; have the same strength (unit deflective charge), rate of detonation, and poisonous gases; and be sensitive enough to detonation and not too sensitive to frictional impact. These attributes are a prerequisite and an assurance of the continuing permissibility of each brand of permissible explosive. Each permissible explosive is submitted by the manufacturer and tested by the Bureau of Mines and may be checked from time to time by the Bureau, which on its own initiative may procure field samples of permissible explosives and check them against the various chemical and physical properties of the explosive as found in Bureau of Mines permissibility tests. The manufacturers have earned a high reputation in this respect. However, the matter of permissibility of an explosive does not end here; the condition of explosive when used may differ materially from that when received from the manufacturer, as the condition of the explosive depends largely upon the manner in which it is stored. Experience has shown that substandard storage conditions injurious to explosives are the rule rather than the exception. Explosives, particularly permissible explosives, should be considered perishable commodities, as extremes of heat, high moisture, or long-time storage affect them adversely. All permissible explosives of the ammonium nitrate class absorb moisture readily in moist, damp, or wet places if the paper wrappers are broken and may become insensitive if stored thus for long periods, especially at temperatures of 90° F. or higher. The absorption of moisture by the ingredients of the cartridge may in a very few days cause a portion of a broken cartridge to become so insensitive that complete detonation of the charge cannot be assured; this often results in misfires, partial misfires, or the burning of a portion of the charge or the entire charge rather than effective detonation.

The operator or user should therefore: (1) Buy explosives in such quantities that they may be used promptly; (2) store the explosives in main storage magazines and distributing magazines so that the oldest stock of any brand may be used first; (3) use the older stock first; (4) transport and handle the explosives so that the wrappers are not broken, preferably in rugged containers such as boxes; (5) subject explosives to moist storage, especially underground, the shortest possible length of time - only the quantity of explosive estimated to be needed for use that day should be taken underground, and any left-over explosive should be returned to the better surface storage at the end of the shift; and (6), if portions of cartridges are used in a hole, use the remaining portion as promptly as possible and when charged in a hole place the cut end of this portion of the cartridge at the bottom of the hole.



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## Prevention of Mine Fires Caused by Explosives

Numerous coal-mine fires have been caused by explosives or by the means used to fire the explosives. Such fires were particularly numerous many years ago when granular black blasting powder was used extensively and often improperly. Fleming and Koster[6] state:

> Furthermore, every mine in the district (Franklin County, Ill.) suffered from frequent fires from the use of black blasting powder, the coal igniting readily and there being some methane liberated at the face. At some mines as many as 25 fires occurred nightly, following the firing of shots, and in two instances 40 were reported. The employment of fire runners to follow the shot firers and extinguish fires became necessary. Four to 10 men were employed for this work at each of the various mines, and the relatively small number of fires getting beyond control speaks well of the efficiency and carefulness of these men and of the officials.

Fires caused directly by black blasting powder or by the fuse or squibs used to fire it and fires following mine explosions caused similarly were very expensive (see Bull. 137, p. 9):

> *** a heavy expense must be charged against explosions and fires from the use of black blasting powder. *** an explosion occurred at shot-firing time, which killed the shot firers and set the mine on fire ***. Both shafts had to be sealed. The shafts were kept sealed for 120 days, and later the mine was flooded ***. The total loss due to flooding, suspension, and restoring the mine to working conditions was upward of $175,000.

The operators and the miners agreed upon an improvement in the method of using black blasting powder, but this gave only partial relief from mine fires, which continued to occur at shot-firing time, even when black blasting powder was used by expert miners under stringent regulations. The introduction of permissible explosives resulted in virtual elimination of mine fires caused during the shot-firing operation. However, some fires did occur with permissible explosives because of the use of excessive charges, little or no stemming, deteriorated (damp) explosives, mixed charges in the same borehole, or fuse and "cap" instead of the electric blasting cap; in other words, the explosives were used in a nonpermissible manner.

Granular black blasting powders continue to cause mine fires. In 1928 a mine in Illinois averaged 3 fires a week from granular black blasting powder and employed fire runners; another Illinois mine was sealed in 1928 because of a fire caused by granular black blasting powder. In 1929 an

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6/ Fleming, J. R., and Koster, J. W., The Use of Permissible Explosives in the Coal Mines of Illinois: Bull. 137, Bureau of Mines, 1917, p. 8.



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Oklahoma coal-mine fire was caused by granular black blasting powder shortly after this explosive had replaced a permissible explosive; and in 1932 an Illinois mine was encountering fires following blasting with granular black blasting powder. These are only a few of many available examples of relatively recent fires due to the use of granular black blasting powder.

Many fires are also caused by the use of that form of black blasting powder designated as pellet powder. In 1931 a fire occurred in an Indiana mine in spite of an inspection made by the shot firer after blasting, because he failed to see the fire on account of the dense smoke; this was duplicated in 1931 in another Indiana mine. In both instances fuse was used for firing the pellet powder, and the fires were not discovered until the second day after the shots had been fired. In other instances fires caused by pellet powder were brought under control either by fighting them directly, in some instances using respiratory protection, or by sealing the immediate area; in one case the pellet powder was fired electrically (electric squib). Recently men were suffocated when they encountered the irrespirable gases produced by a mine fire caused by blasting with pellet powder.

Mine fires are likely to be caused by any form of black blasting powder or by the improper use of permissible explosives; however, they may be prevented by the proper use of permissible explosives. "Proper" use requires (1) permissible explosives in first-class condition; (2) adequate confinement of the charge in a properly placed hole by means of incombustible stemming (if the hole is properly placed, the charge need not be excessive and will not blow out at side or back); (3) correct placement of a properly made primer; and (4) electric firing of the shot by means of electric current which is not potent (or hot) enough to ignite gas, preferably a permissible single-shot blasting unit. All of these conditions have been discussed elsewhere in this circular.

## Electric Firing That Will Not Ignite Gas

Among other provisions, the Mine Safety Board of the Bureau of Mines specifies (Decision 12) that -

> 2. Each shot shall be fired separately by a permissible single-shot blasting unit ***.

The active list of permissible explosives (Report of Investigations 3259) specifies that electric firing must be done by means of a permissible-type blasting unit.

Electric firing has been specified because experience has demonstrated that the accidents resulting from electric firing, as practiced, are not as numerous as those resulting from the use of fuse or squib. This statement is confirmed by Howell's[7/] study of 446 accidents in the anthracite region,

7/ Howell, S. P., Explosives Accidents in the Anthracite Mines of Pennsylvania, 1923-27: Bull. 326, Bureau of Mines, 1931, 93 pp.



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by different methods of firing some 161,000,000 shots. The number of accidents per million shots when squibs were used was 12.2; when fuse was used, 2.7; and when electric firing was employed, 1.9.

During that period the percentages of shots fired by different methods used in the anthracite region were as follows: By squib, 4.4 percent; by fuse, 53.5 percent; by electricity (electric blasting caps, electric squib, and otherwise), 42.1 percent; and by cordeau, much less than 0.01 of 1 percent.

Although electric firing unquestionably is much safer than blasting with fuse or squib, it also presents hazards peculiar to itself. Insofar as the ignition of gas is concerned a hazard arises from the ease with which, under certain conditions, an inflammable mixture of gas and air may be ignited by an arc or spark anywhere along the firing line between the source of power and the hole.

The arc or spark may be produced by a floating short circuit or from commotion at or near the face instantly following the firing of the shot, bringing the two leg wires of the electric blasting cap or wires of the firing cable in contact and breaking this contact while voltage is still on the line. The breaking of this contact may be designated as a "break spark"; the break spark will ignite gas only if the electric current is strong enough, but with permissible single-shot blasting units a break spark anywhere along the shot-firing line is not hot or potent enough to ignite gas. Permissible single-shot blasting units should therefore be used because they are safer as regards ignition of gas or dust and because they are provided with a safety contact, which guards against other types of accidents, particularly premature blasts.

Other sources of electric current, including low-capacity dry cells, which are not strong enough to ignite gas in case of a break spark are available but are not permissible because they have not been provided with a safety contact.

In order that the danger of using a source of electric current capable of producing a break spark strong enough to ignite gas may be fully understood, consider the case of the powerful 10-hole manually operated, nonpermissible magneto. If a single shot is fired the sequence of events is essentially as follows: The current is delivered to the firing circuit at the end of the stroke. In a few thousandths of a second (milliseconds) the shot-firing circuit is open-circuited either by fusing the bridge within the electric blasting cap or breaking it by firing the electric blasting cap. One or more milliseconds thereafter the shot wave set up by the shot is delivered to the surface or the face of the material blasted - for example, the face of the coal. The commotion due to the blast may or may not cause a spark from the legs of the electric blasting cap, the joints where the legs of the electric blasting cap are attached to the firing cable, or along the cable by making contact and separating. Should the bare spots on the leg wires come in contact while there is still voltage on the line -



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there will be voltage on the line if the armature is rotating - a spark or arc will be produced, and if inflammable gas or dust is present it probably will be ignited. One way to reduce this chance of ignition of gas to a minimum is to place the leg wires of the electric blasting cap that extend outside the hole, the joints, and the shot-firing cable so that any commotion will not bring the two sides in contact; that is, they should be placed as far apart as is feasible. Moreover, the shot-firing cable and the leg wires of the electric blasting cap should contain the best insulation possible, and the joints should be staggered. To reduce the possibilities of spark or arc to a minimum, the joints should be staggered; there should be no bare spots on either of the leg wires of the electric blasting cap or the shot-firing cable; and one joint should be removed as far as feasible from the other joint of the line.

Another means of preventing an arc or spark in electrical blasting, utilized extensively in Europe where the equivalent of permissible explosive is employed, is to equip these powerful 10-shot blasting units or blasting units of greater capacity with a timing switch of about 0.03 second inside the case; it is thought in Europe that with reasonable precautions in connecting the cable to the leg wires of the detonator, as previously specified here, and with voltage off the line within 0.03 second the chances of commotion with possible arcing at the face or in the open air are remote.

Some Bureau of Mines engineers favor electrical firing of all shots in a mine simultaneously from outside the mine when nobody is in it.

Special Conditions Requiring Exceptions to Single-Shot Firing

Owing to the importance of certain hazards that attend the firing of shots singly under some conditions the Bureau of Mines, although in favor of firing shots singly as a rule, approves simultaneous multiple shot-firing under certain conditions:[8/]

> Each shot shall be fired separately by a permissible single-shot blasting unit ***.
>
> Where more shots than one are to be fired in a working place of a mine, it is possible that under some conditions special hazards may exist in firing shots separately and inspecting between shots; in such cases simultaneous multiple shot-firing may be allowable, when permitted by the respective State mine regulations. This condition may occur in steeply pitching workings or in working places where outbursts of gas may be released by shot, or where the roof, draw slate, or coal is so friable that despite use of usual good timbering methods falls are likely to occur after a shot, making

8/ Mine Safety Board, Recommendations of the United States Bureau of Mines on Certain Questions of Safety as of February 3, 1933: Inf. Circ. 6732, July 1933, pp. 19-20.



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it dangerous to inspect the roof and to connect the firing leads for the next shot. This possible exception making choice of a lesser hazard does not mean that the Bureau of Mines recommends simultaneous multiple shot-firing when it is at all practicable to fire safely one shot at a time with careful inspection for gas and roof conditions before and after each shot. When multiple shot-firing is necessitated by the conditions it should be done by firing simultaneously with standard electric detonators. The use of fuse and (or) "delayed-action detonators", so called, is dangerous because of the possibility that a delayed shot may ignite gas or a coal-dust cloud thrown out by a previous shot.

No multiple shot-firing device for use in gassy coal mines under this exception has been approved by the Bureau of Mines at the time of completing this paper (May 1933), but an investigation is being conducted to determine its feasibility; meantime, when multiple simultaneous shot-firing is necessitated by the conditions, such available multiple shot-firing device should be selected as will give as low-tension current as possible for firing not to exceed six shots at a time, with duration of current of the smallest fraction of a second. Under no circumstances should the power lines be used in blasting when men are in the mine.

Reason for Limiting the Charge per Hole to 1-1/2 Pounds

All permissible explosives have passed the exceedingly severe test of firing without ignition 1-1/2 pounds repeatedly into an inflammable mixture consisting of 4 percent natural gas, fine bituminous-coal dust, and air; this test places all permissible explosives essentially on a common competitive basis insofar as safety against ignition of gas or dust is concerned. With an adequate number of properly placed holes no hole for blasting in coal need be charged with more than 1-1/2 pounds to do the work satisfactorily; much less than 1-1/2 pounds per hole should be used when feasible, and in many mines this is the practice.

Because this limit - an arbitrary one - has been set, it is sometimes thought that the safety of a permissible explosive is no greater than that of black blasting powder or dynamite when more than 1-1/2 pounds is charged per hole. Actual tests indicate that in general at least 17 times as much permissible explosive as dynamite and at least 45 times as much permissible explosive as black blasting powder are required to place these explosives upon a safety equality; hence a large factor of safety still exists, even when considerably more than 1-1/2 pounds of permissible explosives is used per hole. If permissible explosives are confined adequately in the borehole and the charge is proportioned to the burden the difference in safety between 1-1/2 and 2 pounds of permissible explosive is, in all probability, not much if any greater than the difference in safety between 1 and 1-1/2 pounds of permissible explosive.



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The weight of explosive per hole unquestionably should be kept as low as feasible to serve both safety and efficiency, and enough holes should be used and so placed that no hole requires more than 1-1/2 pounds; however, if this is not possible permissible explosives even if used in quantities greater than 1-1/2 pounds per hole are still much safer than dynamite or black blasting powder under similar conditions.

## Amount of Stemming Required by a Charge

The Bureau of Mines recommends that the shot be confined properly with clay or other incombustible stemming; an absolute minimum length of stemming should be required. It seems essential to safety that the length of stemming in no case should be less than half the length of the charge of explosive and never less than 2 feet. In many instances the hole should be stemmed to the collar.

## Time Between Firing of Nearby Shots

Gas has been ignited by rapid firing of adjacent shots, even with permissible explosives.

The hazard of rapid firing of nearby or adjacent shots lies in the release of explosive gas or dust by shots which have been fired and the firing of a later shot or shots in the presence of gas or dust, or both. Nearby shots therefore should not be fired in immediate succession unless enough time is allowed between each two shots for proper testing of the gas that may have been released by the first shot, for gas to be removed by the air currents, and for the fine, inflammable dust to settle or be rendered inert by rock-dusting or be removed by ventilation. Nearby shots are not necessarily dependent shots, though they often are; the firing of nearby dependent shots is rendered especially hazardous by possible blown-out shots and consequent ignition of gas or dust, as the latter shot may not have an adequate burden, the later shot may open a crack by the firing of the preceding one, or the charge in the later hole may even be exposed by the first shot. Nearby shots that point toward each other should not be fired together because a blown-out shot following a good shot may cause an explosion if it spends itself on the dust or gas, or both, released by the fired shot.

Nearby shots may be fired too rapidly if fired with fuse, even though the two fuses are of supposedly equal length and are lighted simultaneously; likewise, they may be fired too rapidly if delay electric blasting caps are used, even though the delay is of the same period(for example, all first delays). This is one reason why the Bureau considers the use of fuse in firing permissible explosives a nonpermissible practice and the primary reason why it considers the use of delay electric blasting caps as nonpermissible practice.



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Safety in Breaking Boulders or Rock Falls with Explosives

If detached rocks or boulders are too large or too tough to be broken with a sledge they may be blasted safely by using very small charges - 1/4 to 1/2 cartridge of permissible explosive - by blockholing; a hole or holes should be drilled in the rock with bottom not too close to the side of the rock away from that in which the hole is started, and each hole should be stemmed with incombustible material to the collar. To insure greater safety, several pounds of rock dust should also be placed on the rock above the boreholes to act mainly as exterior stemming and to cool the flame of a possible blown-out shot.

In no case should bulldozing shots (mudcapped, adobe, crevice, groove, plaster, lay-on, "shock", or open shots) be permitted in any coal mine, as they are extremely dangerous, even where no explosive gas is present. Shots of this type should be prohibited, partly because they are inefficient but primarily because they ignite gas or dust so readily that even the use of rock dust or other incombustible material over the charge does not insure that degree of safety to which men and mine are entitled. Certainly no shots of this type should ever be fired with the working shift in the mine.

Harrington and Owings[9/] have called attention to a number of explosions and other accidents from mudcapped shots in coal mines. Although high explosives other than permissible explosives have usually been involved bulldozing shots of permissible explosives have caused explosions.

Bulldozing of rock or coal in place is just as hazardous as bulldozing detached rocks or boulders; to insure safety in coal mines blasting should be done only with permissible explosives properly confined in boreholes.

## EXPERIENCE IN USE OF PERMISSIBLE EXPLOSIVES

The following sections of this report include an estimate of the experience in the use of permissible explosives, statements regarding the quantity of explosives used for blasting in coal mines, the percentage (estimated) of coal blasted by permissible explosives, the percentage (estimated) of shots of permissible explosives fired in hazardous places, such as gassy or dusty mines or gassy or dusty sections or places in mines, by comparison with other explosives, and the number of accidents caused directly by the explosives.

The record of gas or dust ignitions from black blasting powder, dynamite, and permissible explosives is taken from such reports as are available to the Bureau of Mines. These data show that no permissible explosives when used in a permissible manner have caused an ignition of either gas or dust and that no gas ignition has occurred from permissible explosives unless two or more nonpermissible conditions existed during their use.

9/ Harrington, D., and Owings, C. W., Explosions and Other Accidents from Mudcapped Shots in Coal Mines: Inf. Circ. 6158, Bureau of Mines, 1929, 5 pp.



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## Explosives Used and Explosives Accidents, 1912-32

In 1902 the first "short-flame" explosives were used in the United States, the quantity aggregating 11,300 pounds. In 1909 the first permissible explosives were used, the quantity sold reaching 9 million pounds; in 1913 more than 20 million pounds were used in coal mines. Comparison of the quantities of black blasting powder, high explosives (other than permissible explosives), and permissible explosives sold for use in coal mines from 1912 to 1932 show that sales of black blasting powder have always greatly exceeded sales of either high explosives or permissible explosives. Sales of black blasting powder declined slowly from 1912 to 1915, reached a maximum of 235,750,300 pounds in 1917, and fluctuated with the erratic production of coal from 1918 to 1923, standing at 175,488,750 pounds in the latter year; since 1923, however, they have decreased rapidly and rather uniformly, irrespective of whether the production of coal remained high, as it did from 1923 to 1929, or whether the production declined markedly, as it has done since 1929. In 1929 sales of black blasting powder aggregated 102,060,255 pounds and in 1932; 56,311,975 pounds.

From 1912 to 1932 sales of high explosives (other than permissible explosives) for use in coal mines ranged from 37,828,979 pounds in 1923 to 16,173,014 pounds in 1932. Since 1926 the quantity decreased steadily from 35,228,899 pounds. A large proportion of the high explosives (mostly dynamite) now consumed in coal mining in the United States is used for rockwork in the Pennsylvania anthracite mines.

Sales of permissible explosives for use in coal mines of the United States increased from 1912 until 1926, when a maximum of 65,143,319 pounds was reached, and declined steadily to 31,532,816 pounds in 1932. Sales have fluctuated with total coal production, showing a decidedly upward trend until 1929. Since 1915 the quantity of permissible explosives used in coal mines has exceeded the quantity of high explosives and since 1924 has been about twice as much.

Coal production increased markedly from 1914 to the 1918 peak of 678,211,904 short tons, was erratic until 1926, and declined markedly from 1926 to 1932, except for 1929. In 1932 the production was 359,565,000 short tons. Obviously sales of explosives for use in coal mines have kept close pace with coal production.

Table 1 shows the number of coal-mine fatalities in the United States involving explosives for the period 1916-31. These fatalities show a general downward trend from a maximum of 241 in 1919 (very high due to the "powder" explosion in the Baltimore No. 2 tunnel in Pennsylvania, which caused 92 fatalities) to a minimum of 47 in 1931; in general, the downward trend of fatalities from explosions coincides fairly closely with the reduction in the use of black blasting powder, although other factors have some significance.



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Table 1. - Number of coal-mine fatalities in the United States involving explosives, 1916-31

| Year | Fatalities due directly to explosives | | | Fatalities from gas and dust explosions due to explosives or blasting | Total |
|---|---|---|---|---|---|
| | Underground | On surface | Total | | |
| 1916 | 146 | 2 | 148 | 32 | 180 |
| 1917 | 110 | 13 | 123 | 26 | 149 |
| 1918 | 135 | 11 | 146 | 40 | 186 |
| 1919 | 206 | 1 | 207 | 34 | 241 |
| 1920 | 131 | 11 | 142 | 48 | 190 |
| 1921 | 142 | 5 | 147 | 30 | 177 |
| 1922 | 93 | 9 | 102 | 67 | 169 |
| 1923 | 115 | 10 | 125 | 39 | 164 |
| 1924 | 99 | 3 | 102 | 25 | 127 |
| 1925 | 102 | 6 | 108 | 93 | 201 |
| 1926 | 96 | 2 | 98 | 54 | 152 |
| 1927 | 110 | 5 | 115 | 21 | 136 |
| 1928 | 74 | 2 | 76 | 16 | 92 |
| 1929 | 88 | 5 | 93 | 7 | 100 |
| 1930 | 78 | 4 | 82 | 10 | 92 |
| 1931 | 40 | 1 | 41 | 6 | 47 |
| Total | 1,765 | 90 | 1,855 | 548 | 2,403 |
| Average | 110 | 6 | 116 | 34 | 150 |
| Percentage | 73.5 | 3.7 | 77.2 | 22.8 | 100.0 |

The reduction in number of fatalities from coal-mine blasting is due largely to a reduction in underground fatalities caused directly by explosives but is influenced favorably by a large proportional, but small aggregate, reduction in fatalities on the surface directly attributable to explosives and by a substantial reduction in fatalities attributable to dust and gas explosions initiated by explosives or blasting. (See table 1.) Underground fatalities in recent years have been decreased materially owing to the use of proportionately less black blasting powder and dynamite, greater care in transportation and handling of all explosives, increased use of electric blasting, knowledge of the hazards of electric blasting (it does present hazards, particularly in connection with premature shots) and how to guard against them, safer blasting methods, and probably better instruction and supervision.

The reduction in the number of fatalities from gas and dust explosions caused by explosives and blasting in recent years is due partly to increased use of permissible explosives, wider use of permissible explosives in dangerous mines or in hazardous places (gassy or dusty, or both) in mines, adoption



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of rock-dusting in some of the more hazardous mines or sections of mines, more intensive and more intelligent inspection given the operating practices of many dangerous mines, better blasting practices, and efficient ventilation and gas testing resulting from improved instruction and supervision.

Machine mining increases the efficiency of explosives considerably, permits the use of relatively small charges, and therefore contributes largely to a reduction in the quantity of explosives used per 1,000 tons of coal mined; this in turn aids safety in the use of explosives, particularly where permissible explosives fired electrically are employed skillfully and substituted for black blasting powder and dynamite.

Mechanical loading, however, often tends to increase the hazards of blasting by interfering with efficient ventilation, releasing firedamp rapidly through rapid extraction, creating a hazardous dusty condition, firing an increased number of shots daily in the same place, using dependent shots or delay electric blasting "caps" or both, and usually requiring blasting during the main working shift. The most intensive and competent supervision of the blasting operation is required to prevent gas or dust ignitions and premature blasts when firing electrically, which is hazardous with mechanical loading because the latter generally utilizes electricity as power close to places where holes are charged and blasted.

The proportionately greater increase in the use of permissible explosives in the anthracite region of Pennsylvania compared with bituminous-coal mines in the United States is shown in table 2 for 1917-32. Anthracite mines consumed 17 percent of the total amount of permissible explosives used in coal mining in 1917, a minimum of 15.9 percent in 1920 and a maximum of 41.2 percent in 1932; use of permissible explosives in bituminous mines fluctuated from a maximum of 76.0 percent of the total in 1922 to a minimum of 56.7 percent in 1932. It is significant that of the total quantity of permissible explosives manufactured 76.6 percent was used in coal mines in 1917 and 97.9 percent in 1932; the explanation of this is that special explosives and explosives similar to permissible explosives, but not so denominated, are now used to a considerable extent in place of permissible explosives in metal and nonmetal mining and in railroad, quarrying, and other construction work.

Table 2. - Percentage of total quantity of permissible explosives manufactured which was used in anthracite and bituminous coal mines, 1917-32[1/]

| Year | Percentage used in | | | Year | Percentage used in - | | |
|---|---|---|---|---|---|---|---|
| | Anthracite mines | Bituminous-coal mines | All coal mines | | Anthracite mines | Bituminous-coal mines | All coal mines |
| 1917 | 17.0 | 59.6 | 76.6 | 1925 | 20.7 | 68.9 | 89.6 |
| 1918 | 16.6 | 64.3 | 80.9 | 1926 | 28.2 | 68.0 | 96.2 |
| 1919 | 22.1 | 62.4 | 84.5 | 1927 | 29.4 | 66.0 | 95.4 |
| 1920 | 15.9 | 67.9 | 83.8 | 1928 | 31.8 | 62.5 | 94.3 |
| 1921 | 29.0 | 63.5 | 92.5 | 1929 | 30.8 | 65.3 | 96.1 |
| 1922 | 16.6 | 76.0 | 92.6 | 1930 | 31.9 | 65.4 | 97.3 |
| 1923 | 24.2 | 69.9 | 94.1 | 1931 | 37.6 | 60.1 | 97.7 |
| 1924 | 30.7 | 63.9 | 94.6 | 1932 | 41.2 | 56.7 | 97.9 |

1/ This table does not indicate the relative amount of permissible and nonpermissible explosives used in coal mines, or the relative amounts of coal produced by the different kinds of explosives.



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## EXPLOSIVES USED IN ANTHRACITE REGION OF PENNSYLVANIA, 1917-32

The record of the amount of black blasting powder, high explosives, and permissible explosives sold for use in the anthracite mines of Pennsylvania per 1,000 short tons of anthracite mined shows some highly significant trends. The quantity of black blasting powder sold per thousand tons of anthracite has decreased from a maximum of 359 in 1917 to a minimum of 152 pounds in 1932; the quantity of high explosives has increased from 162 in 1917 to a maximum of 323 pounds in 1927 and 1929 and has decreased since 1929 to 226 pounds in 1932; the quantity of permissible explosives has increased steadily from 73 in 1917 to a maximum of 269 pounds in 1932, although a reduction is noted for 1930. The trend in the use of black blasting powder shifted upward in 1929 and 1930, owing largely to the increased use of pellet powder, but since 1929 has been markedly downward. The downward trend in use of high explosives per thousand short tons of anthracite since 1929 is due partly to the substitution of more powerful types of permissible explosives in chute blasting but chiefly to a progressive reduction of rock work.

The increased use of permissible explosives in the anthracite region is an encouraging feature of the story of permissible explosives and of progress in safety in anthracite mining. By 1926 the quantity of permissible explosives per 1,000 pounds in anthracite mining exceeded that of black blasting powder; by 1931 it equaled the quantity of high explosives used, and in 1932 it exceeded the quantity of high explosives used. Its use has increased because of more general recognition of the adaptability of permissible explosives for all blasting purposes, a much greater safety in gassy places, fewer gas ignitions compared with black blasting powder, a substantial increase in electric blasting because of its greater safety, and the greater strength inherent in certain permissible explosives of the gelatine type. Many anthracite collieries use permissible explosives exclusively in blasting coal, and many collieries - in some instances all the collieries of a State inspection district - fire all shots electrically. Incidentally, electric firing is the only logical method of firing shots where closed lights are used exclusively and an effort is made to keep matches and smoking out of the mine, inasmuch as the use of matches in smoking is a major cause of gas explosions in the anthracite region. However, use of electric firing and electric cap lamps and failure in the necessary measures to exclude matches and smoking are certain to result in gas ignitions in any coal mines in which gas occurs.

From 1917 to 1932 anthracite production varied materially, but the trend was generally downward - 99,611,811 short tons in 1917 to 49,855,221 in 1932, with very low yearly production in 1922 and 1925. The low production in these years was made with much less explosives per 1,000 tons, possibly because development work was discontinued temporarily, considerable coal, previously blasted, was drawn from full breast, and other means were adopted to decrease cost.



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The percentage of anthracite mined with permissible explosives was estimated on the following basis: That 25 percent of the high explosives was used in coal mining including chute blasting, that virtually all black blasting powder and "permissibles" were used in blasting coal, and that in blasting coal 1 pound of permissible was equivalent to 1 pound of high explosives and 1-3/4 pounds of black blasting powder. This estimate shows a progressive and rather uniform upward trend in the anthracite obtained through use of permissible explosives from 23 percent in 1917 to 65 percent in 1932. With full recognition of all the hazards attending the storage, handling, and use of black blasting powder, the greater hazard of chute blasting with dynamite than with permissible explosives, and the assurance that electric blasting can be accomplished safely, the percentage of anthracite mined with permissible explosives fired electrically probably will increase steadily above the estimated 65 percent in 1932. The yearly variations are shown in table 3.



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TABLE 3. - Estimated quantity and percentage of explosives used by classes in anthracite and bituminous-coal mines in the United States, 1917-32

| Year | Anthracite mines | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Pounds per thousand tons | | | Percent of explosive sold for use | | | Percent of coal blasted with permissible explosive | Production, short tons |
| | Permissible | High explosive | Black blasting powder | Permissible | High explosive | Black blasting powder | | |
| 1917 | 73 | 162 | 359 | 12.3 | 27.3 | 60.4 | 23 | 99,611,811 |
| 1918 | 77 | 169 | 307 | 13.9 | 30.6 | 55.5 | 26 | 98,826,084 |
| 1919 | 98 | 202 | 289 | 16.6 | 34.3 | 49.1 | 31 | 88,092,201 |
| 1920 | 95 | 215 | 258 | 16.7 | 37.9 | 45.4 | 32 | 89,598,249 |
| 1921 | 132 | 252 | 264 | 20.4 | 38.9 | 40.7 | 38 | 90,473,451 |
| 1922 | 132 | 228 | 231 | 22.3 | 38.6 | 39.1 | 41 | 54,683,022 |
| 1923 | 156 | 274 | 233 | 23.5 | 41.3 | 35.2 | 43 | 93,339,009 |
| 1924 | 192 | 305 | 229 | 26.5 | 42.0 | 31.5 | 48 | 87,926,862 |
| 1925 | 195 | 288 | 206 | 28.3 | 41.8 | 29.9 | 51 | 61,817,149 |
| 1926 | 226 | 310 | 201 | 30.7 | 42.0 | 27.3 | 54 | 84,437,452 |
| 1927 | 235 | 323 | 187 | 31.5 | 43.4 | 25.1 | 55 | 80,095,564 |
| 1928 | 251 | 302 | 182 | 34.1 | 41.1 | 24.8 | 58 | 76,734,000 |
| 1929 | 262 | 323 | 201 | 33.3 | 41.1 | 25.6 | 57 | 73,828,195 |
| 1930 | 247 | 311 | 197 | 32.7 | 41.2 | 26.1 | 57 | 69,384,837 |
| 1931 | 262 | 261 | 173 | 37.7 | 37.5 | 24.8 | 61 | 59,645,652 |
| 1932 | 269 | 236 | 152 | 41.0 | 35.9 | 23.1 | 65 | 49,855,221 |
| | Bituminous-coal mines | | | | | | | |
| 1917 | 47 | 22 | 362 | 10.9 | 5.1 | 84.0 | 19 | 551,790,563 |
| 1918 | 51 | 25 | 321 | 12.8 | 6.3 | 80.9 | 21 | 579,385,820 |
| 1919 | 52 | 25 | 275 | 14.8 | 7.1 | 78.1 | 25 | 465,860,058 |
| 1920 | 64 | 32 | 346 | 14.5 | 7.2 | 78.3 | 24 | 568,666,683 |
| 1921 | 63 | 27 | 280 | 17.0 | 7.3 | 75.7 | 28 | 415,921,950 |
| 1922 | 78 | 31 | 337 | 17.5 | 6.9 | 75.6 | 29 | 422,268,099 |
| 1923 | 75 | 22 | 272 | 20.3 | 6.0 | 73.7 | 33 | 564,564,662 |
| 1924 | 73 | 20 | 249 | 21.3 | 5.9 | 72.8 | 34 | 483,686,538 |
| 1925 | 77 | 18 | 230 | 23.7 | 5.5 | 70.8 | 37 | 520,052,741 |
| 1926 | 80 | 16 | 208 | 26.3 | 5.3 | 68.4 | 40 | 573,366,985 |
| 1927 | 81 | 16 | 189 | 28.3 | 5.6 | 66.1 | 43 | 517,763,352 |
| 1928 | 77 | 14 | 177 | 28.7 | 5.2 | 66.1 | 43 | 492,755,000 |
| 1929 | 76 | 15 | 163 | 29.9 | 5.9 | 64.2 | 45 | 534,988,593 |
| 1930 | 75 | 14 | 154 | 30.9 | 5.8 | 63.3 | 46 | 467,526,299 |
| 1931 | 65 | 12 | 152 | 28.6 | 5.3 | 66.1 | 43 | 382,089,396 |
| 1932 | 60 | 15 | 159 | 25.6 | 6.4 | 68.0 | 40 | 309,709,872 |



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## EXPLOSIVES USED IN BITUMINOUS-COAL MINES IN THE UNITED STATES, 1917-32

The trend of the quantity of the three classes of explosives used per 1,000 short tons of bituminous coal mined from 1917 to 1932 (table 3) was: For black blasting powder, a maximum of 362 pounds in 1917, an erratic decrease to 272 pounds in 1923, a decided decrease to 154 pounds in 1930, and a slight increase from 152 pounds in 1931 to 159 pounds in 1932; for high explosives, an upward tendency from 22 pounds in 1917 to 32 pounds in 1920, a decrease to 12 pounds in 1931, and a slight increase to 15 pounds in 1932; for permissible explosives, an erratic increase from 47 pounds in 1917 to a maximum of 81 pounds in 1927 and a decrease, rapid after 1930, to 60 pounds in 1932.

The quantity of permissible explosives used in the coal mines of the United States has never equaled half the quantity of black blasting powder so used, although it approached the quantity of black blasting powder in 1930. Permissible explosives in general gained steadily on high explosives from 1917 to 1932, obviously because of the substitution of the former in rockwork and elimination of much of the rockwork in which high explosives would ordinarily be employed. Black blasting powder retains its supremacy in quantity used, largely because it costs less and can be (and generally is) fired with fuse or squib or even fuse and caps, each usually costing less than electric blasting caps, and because most operators believe it will produce more lump coal or lumps of greater solidity and less slack coal than permissible explosives. Permissible explosives, however, if used skillfully, have no peer in producing lump coal in machine-mined places; elsewhere they are either on a par with black blasting powder or but little less efficient. Even under unfavorable conditions as to quality of coal produced the far greater safety of permissible explosives is a small price to pay for any relatively slight uneconomic feature that may be involved. Permissible explosives are used largely for blasting machine-mined coal, for blasting in gassy or dusty places, and for blasting top, bottom, or intermediate bands of rock in coal mining. The great range of the strength characteristics of permissible explosives favors their use for the variety of blasting conditions encountered in bituminous and lignitic mines in the United States.

The percentage of bituminous coal mined with permissible explosives was estimated on the following basis: That all coal was mined with either permissible explosives or black blasting powder, that 1 pound of permissible explosive was equivalent to 1-3/4 pounds of black blasting powder, and that the permissible explosives used in blasting rock were more than compensated by the high efficiency obtained with them in blasting machine-mined coal. This estimate shows that in 1917 about 19 percent of the bituminous coal was blasted with permissibles and that the percentage rose rather steadily to about 46 percent in 1930 and then declined to approximately 40 percent in 1932.

Apparently permissible explosives have lost ground since 1930 in the bituminous mines in the United States but have gained in the anthracite region in Pennsylvania.



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## PERMISSIBLE EXPLOSIVES USED UNDER HAZARDOUS CONDITIONS

Permissible explosives are more efficient, pound for pound, than black blasting powder, and where used under similar conditions the proportion of coal blasted with permissibles is correspondingly greater for both anthracite and bituminous-coal mines.

It is important, however, to stress the fact that a large percentage of the coal from gassy or dusty mines is blasted with permissible explosives. The opportunities for gas or dust ignitions are therefore more frequent with permissible explosives than with either black blasting powder or dynamite; it is estimated that permissible explosives as now used have at least 90 percent of these maximum opportunities to ignite gas or dust. In view of the hazardous conditions which generally attend the use of permissible explosives and the nonpermissible conditions under which they frequently are used it would not be surprising if a large proportion of the ignitions of gas or dust in coal mines were caused by permissible explosives; such, however, is not the case, as stated in the introduction to this circular.

The Bureau of Mines has a record of 117 coal-mine explosions caused by explosives in the United States from 1908 through 1932. Of these 12 were in anthracite mines and 105 in bituminous-coal mines; only 13 are chargeable to permissible explosives used in a nonpermissible manner and 2 to permissible blasting devices used likewise. In these 117 explosions 1,136 men were fatally injured and 235 men were nonfatally injured.

Of the 13 explosions known to have occurred when permissible explosives were used (all in a nonpermissible way) 7 were gas explosions, 1 was a dust explosion, 4 were gas and dust explosions, and 1 was an air blast caused by a greatly overcharged shot.

In all instances in which gas or dust was ignited the explosives were fired in gas, but in each one of these instances as well as those in which dust was ignited additional nonpermissible conditions of use - sometimes as many as three - were in effect. In 4 instances the shots were obviously likely to blow out, in 1 the hole was not stemmed to the collar, in 1 combustible stemming was used, in 6 the shot was overcharged, in 1 and possibly 2 adjacent shots were fired rapidly, using electric firing. In 1 instance adjacent shots were fired rapidly by fuse, in 1 tests were not made for gas, in 5 - all gas ignitions - a nonpermissible shot-firing device was used and possibly the gas was ignited by the current used for firing electrically, in 3 live currents were used for firing, and in 2 the charge was not in a borehole (that is, they were "bulldozing" shots).

## SUMMARY

1. According to results of gallery tests the factor of safety against ignition of inflammable gas by permissible explosives over black blasting powder is at least 45 and over common dynamite at least 17.



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2. Experience has shown that no permissible explosives when used in a permissible manner have caused ignition of either gas or dust in any coal mine in the United States and that no gas ignition has occurred from permissible explosives except where 2 to 4 nonpermissible conditions existed during their use.

3. Coal-mine fatalities from explosives show a decidedly general downward trend, from a maximum of 241 in 1919 to a minimum of 47 in 1931. The downward trend coincides fairly closely with the reduction in sales of black blasting powder. Gas and dust explosions due to explosives caused 22.8 percent of the fatalities from explosives in the period 1919-31, inclusive.

4. The reduction in the number of fatalities from gas and dust explosions caused by explosives or blasting is due chiefly to the increased use of permissible explosives, particularly in hazardous places (gassy or dusty, or both); adequate rock-dusting in some of the more hazardous mines or sections; greater care in transportation and handling of all explosives; increasing use of electric blasting, with a knowledge of its hazards and how to guard against them; and better blasting practice (including ventilation and gas testing) resulting from improved instruction and supervision.

5. To insure maximum safety in the use of permissible explosives, the following should be observed:

(a) Permissible explosives should be fired electrically, as accidents are not as numerous when they are so fired as when fuse and blasting caps are used.

(b) The electrical current used for firing should not be potent enough to ignite inflammable gas in the event of a break spark.

(c) The safest blasting system is that of taking the explosive into the mine and loading it into the blasting holes after the working shift has left the mine and of firing all shots simultaneously from outside when nobody is in the mine.

(d) Permissible explosives should not be fired in a dangerous percentage of firedamp.

(e) Ignition of inflammable coal dust should be guarded against by the use of water on the cutter chain and on and at the face and by rock-dusting.

(f) Charges should be properly confined in boreholes and stemmed with incombustible material.

(g) The explosive should be in first-class condition when used; in other words, deteriorated explosives should not be used.



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(h) The charge of permissible explosive per hole should be limited to 1-1/2 pounds as a maximum.

(i) The face should be properly prepared for blasting.

(j) The primer should be properly prepared and located in the hole.

(k) There should be an adequate number of properly placed holes, each of adequate gage, to permit ready placement of the charge.

(l) Competent shot firers only should charge and tamp holes; the competence of such shot firers should be attested by a State certificate as mine examiner, fireboss, or foreman. As an alternative the shots may be charged and the holes tamped under the immediate supervision of a man so qualified. The shot firers should at all times be under close supervision and discipline.

(m) Both before and after charging a hole the shot firer should assure himself by a suitable test, such as one employing a permissible flame safety lamp, that no explosive gas is present; if he finds gas in quantities that indicate danger the hole should not be charged, and if he finds gas after the hole is charged the shot should not be fired. Holes may be charged and shots fired, however, after the gas has been removed by ventilation.

(n) The methods of firing shots in coal mines in the order of preference are: Charging by shot firers after the working shift and firing from the surface with all men out of the mine; charging and firing by shot firers when all other men are out of the mine; charging and firing by shot firers on the off shift; charging and firing by shot firers on the regular or main shift; charging by miners during the shift and firing by shot firers when all other men are out of the mine; charging and firing by miners at the end of the shift or at some specified time during the shift, such as midday. The method of charging and firing by miners at any time during the shift, although practiced in many mines, is neither safe nor efficient and therefore is the least preferred.

(o) Except when firing from outside the mine, shots preferably should be fired singly by a permissible single-shot blasting unit, and nearby shots should not be fired in rapid succession.

(p) Permissible shot-firing units (unless firing is done from the surface) should be used by either shot firers or miners. Such units provide electric current that is not potent enough to ignite gas or break sparks, and they do not have exposed terminals which may cause premature blasts.



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(q) The use of the power lines for blasting in coal mines is distinctly hazardous unless utmost care is taken; the power wires should not be used for blasting in coal mines when men are in the mine.

(r) Shot firers or miners should not return to the face too promptly after firing, as a single shot may under abnormal conditions explode twice, the smoke and dust may so obscure the roof and face that approach is hazardous, or the noxious gases and fumes may not have been adequately diluted by ventilation and rendered harmless.

(s) The electrical short circuit on the legs of the electric blasting cap should not be removed until just before the leg wires are connected to the shot-firing cable.

(t) The shot-firing cable should be at least 100 feet long; it should be kept in good repair and should be detached from the source of the firing current at all times except at the instant that a shot is being fired.

(u) Shots should be properly guarded, and the intention to fire should be declared in a standardized manner.

(v) Bulldozing or other open, unconfined shots should not be fired in any coal mine.

6. Misfires may be reduced by selecting proper explosives and electric blasting caps, by keeping them in first-class condition through proper storage until used, by using the explosive before it has aged unduly, and by correct priming, charging, and firing of the explosive.

7. In this circular an attempt has been made to estimate the present status of the use of permissible explosives, compared with their use in previous years and with the use of nonpermissible explosives for anthracite, bituminous, and all coal mines.

8. Since 1915 the quantity of permissible explosives used in coal mines has always exceeded that of high explosives, and since 1924 about twice as much permissible explosive as dynamite has been used. Sales of black blasting powder for mining purposes have always greatly exceeded sales of either high explosives or "permissibles."

9. Permissible explosives are not unduly sensitive to frictional impact but are sensitive enough to detonation not to promote misfires; their sensitiveness may be impaired by improper storage.

10. Permissible explosives of classes 1 and 6 are not ignited readily, do not burn vigorously after ignition, and will not explode promptly upon ignition. The black blasting powders, however, do not exhibit any of these favorable characteristics.



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11. The proper brand of permissible explosive should be selected for use. Permissible explosives have a wide range of physical characteristics and are adaptable to essentially every type of blasting in coal mines. The proportion of prepared sizes of coal produced depends upon the skillful application of a suitable brand of permissible explosive.

12. Class A or B (basis, volume of poisonous gases), preferably class A, permissible explosives should be used in poorly ventilated places.

13. The hazard of gas ignition can be reduced substantially by the use of "sheathed" permissible explosives.

14. Neither dynamite nor any type of black blasting powder should be used for any purpose in any underground coal mine; suitable types of permissible explosives are available to perform any explosive function in any coal mine. The vastly superior safety qualities of permissible explosives over those of any dynamite or black blasting powder now available make it imperative that only permissible explosives be used in underground coal mines.



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